

A New Approach to Quantifying Riparian Buffers in the Rural-Urban Fringe in the Lower Fraser Valley

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Abstract

The importance of riparian buffers to protect water quality and fish habitat in agricultural areas is well documented. However, when setting protection and restoration priorities it is not easy for community groups and governments to assess which buffers are the most effective and why. The objective of this study was to develop a set of easily measured indicators that could be used to set priorities. Land-based indicators that other studies have shown to have an effect on riparian buffer functions and can be quickly measured in a Geographic Information System (GIS) were selected. Indicators were measured at two scales: the reach and riparian corridor. These indicators were compared with water quality and in-stream physical habitat to assess their ability to predict in-stream conditions in three watersheds in the Lower Fraser Valley, British Columbia. Six key indicators were identified that predict the effectiveness of the riparian buffer. Significant relationships were found between percent channelization, percent forest and percent agriculture and dissolved oxygen; the number of barns per kilometer and ammonia; forest cover conditions and stream temperature; and percent of forest cover and the number of pieces of large woody debris and habitat complexity. Land indicator conditions of the reach were found to be better predictors of in-stream physical habitat, whereas land indicator conditions of the riparian corridor were found to be better predictors of water quality. An easy-to-use assessment procedure for stakeholders to set restoration and protection priorities for riparian buffers was developed based on the observed relationships and thresholds.

Introduction

A riparian buffer is a vegetated zone occurring between a waterway and an adjacent area that is impacted by adjacent land uses (Castelle et al. 1994). It may extend past the natural riparian area. Through numerous research efforts many functions of riparian buffers have been documented from minimizing temperature fluctuations, to providing structural stream elements, to capturing nutrient runoff (Barton et al. 1985; Castelle et al. 1994; Hachmoller et al. 1991; Fennessey and Cronk 1997; Millar et al. 1997; Osborne & Kovacic 1993; Snyder et al. 1998; Wegner 1999). A variety of land uses and impacts may alter the effectiveness of the riparian buffer, such as drainage patterns, impervious surfaces, vegetation types and agricultural practices.

The encroachment of agricultural land uses into the riparian buffer decrease its viability. Forest cover and wetlands have decreased significantly since European settlement in the 19th century with the increase of agricultural and urban areas (Boyle et al. 1997). In agricultural areas activities such as maximizing arable land, channelization of the stream, drainage tiles piped directly to the stream and vegetation removal reduce the effectiveness of the riparian buffer to enhance habitat diversity and filter nutrients and sediment (Bolton and Shellberg 2002; Stauffer et al. 2000). The intensification of agriculture puts further pressure on existing riparian buffers. In the Lower Fraser Valley agricultural intensification is evident in census data, for example the number of chickens per hectare by all farms in the Lower Fraser Valley changed by +39% from 1986 to 1996 (Schreier et al., 2003).

Protection of existing buffers is an important method to minimize the impacts of agricultural intensification and urban encroachment. Riparian and aquatic ecosystems are currently being impacted at a greater rate than ever before (Kauffman, 1997). In the U.S. 70-90 % of riparian areas have been significantly altered. Where buffers have been impacted stream restoration is commonly employed as a method to attempt to re-establish the structure and function of a stream ecosystem (Zandbergen 2000; Nehlsen 1997). Restoration is labour intensive and expensive, therefore it is important to select areas that have the greatest potential for success.

A riparian buffer assessment provides a method for highlighting areas where riparian buffers are currently functioning well and areas where stream restoration could enhance the buffer. Few riparian buffer assessments have been developed, particularly in agricultural areas in the Pacific Northwest. A similar assessment, the Index of Riparian Integrity (IRI), focused on urban impacts was developed in Western Washington (May et al. 1997). A riparian buffer assessment typically employs a set of indicators that can be used to predict and compare the integrity of a stream. Indicators allow us to efficiently measure a few key parameters, as opposed to exhaustively sampling every conceivable, measurable parameter

for use in investigating broad-scale issues (Cairns et al. 1993; Innis et al. 2000). A number of indicators are usually used to improve predictability (Kelly and Harwell 1990; Karr 1993).

Determining the scale to measure indicators often proves difficult. Studies have shown that the influence of environmental factors on stream quality may act at a number of scales including watershed, riparian corridor and reach (Lammert and Allan 1999; Richards et al. 1996; Allan et al. 1997). Frissel et al. (1986) speculates that habitat and shade characteristics are affected by the local, reach scale, whereas temperature moderation, nutrient retention and channel form are affected by the regional or catchment scale. Successful restoration projects require attention to local and watershed-scale goals (Kauffmann et al. 1997). In order to effectively develop indicators to predict the effectiveness of a riparian buffer at protecting both water quality and physical fish habitat parameters a variety of scales must be employed.

The objectives of this study were to select a suite of land-based indicators that could potentially represent the effectiveness of a riparian buffer to maintain water quality and fish habitat; to investigate relationships between the land based indicators and water quality and in-stream physical habitat parameters; to determine the appropriate scale to measure the indicators at; to develop significant relationships and evidence of thresholds into an easy to apply riparian buffer effectiveness assessment. The study was carried out in three predominantly agricultural watersheds in the Lower Fraser Valley, British Columbia.

Methods

Study sites

Sites were established in three watersheds in the Lower Fraser Valley, British Columbia: Elk Creek, Miami River and Salmon River Watersheds. These watersheds are predominantly agricultural with low density residential areas. The Elk Creek watershed has steep, forested headwaters that flow into a lower gradient, open, agricultural area in the lower watershed. The Miami River Watershed begins amongst flat, open agricultural land uses, flows through a forested area and out alongside a small town, Harrison Hot Springs. The Salmon River Watershed begins in a low gradient agricultural area. Downstream agricultural and residential areas predominate with an extensive forested buffer. The lower Salmon Watershed is dominated by flat, open agriculture. The agriculture in the three watersheds is mainly dairy and chicken barns, pasture, corn, berry and hobby farms.

Indicator selection and sampling

Indicators were selected that could be easily sampled using orthophotos and GIS. Other studies that have demonstrated which indicators may affect the following four stream functions: stabilizing stream banks, capturing nutrients and sediment, providing structural diversity in the stream, and moderating stream temperature were used to further focus the initial indicator selection. The following indicators were selected from an original larger set: percent forest; percent shrub; percent agriculture; percent pasture; percent row crop; percent channelization; and the number of barns (see Elliott, 2003 for more information). Indicators of urban impacts, percent impervious areas and number of breaks, were initially included, however due to the lack of in-stream parameters, peak flows and benthic invertebrates sampled that could reflect these urban impacts were not studied further.

These indicators were sampled at the reach and riparian corridor scale. The riparian corridor was selected over the watershed scale because other studies have found it to be equally if not more predictive than the watershed, and it is simpler to measure. Johnson et al. (1997) and Addah (2002) found the riparian corridor to be an equal or better predictor of water quality than the watershed. At both the reach and riparian corridor scales the indicators were sampled in a 30m wide buffer on either side of the stream. At the reach scale indicators were sampled 200m upstream from the water quality site. At the riparian corridor scale indicators were sampled the entire distance upstream of the station to the headwaters. The number of barns were counted within the two scales. At the riparian corridor scale the barns were recorded as per km. Percent channelization is the length of stream that has been straightened divided by the total length. The percentage of land cover and land use variables were simply calculated by dividing the area that these indicators occupied by the total area at the scale of sampling.

In-stream sampling

In-stream sampling was used to determine the validity of the selected indicators. Water quality was sampled in September 2001, November 2001 and February 2002 at 35 sites. November sampling was used in the analysis presented, with the exception of stream temperature, which was analyzed using the September data. The water quality parameters that were sampled and used within the analysis were: dissolved oxygen, temperature, ammonia and nitrate. Stream temperature was also recorded hourly at 12 of the 35 sites using temperature loggers in August 2001 and 2002. Out of the 35 water quality sites a subset of 27 accessible sites (the widest sites were removed) were sampled for physical habitat parameters. These

27 sites had a mean gradient of 1.3 degrees and a mean width of 5.9 m. Physical habitat was sampled in a reach 300m upstream from the water quality stations. The physical habitat parameters that were sampled and used in this analysis were large woody debris (LWD) and habitat complexity. LWD was recorded as the number of pieces of wood equal to or longer than 2 m and with a diameter greater than or equal to 10 cm. Habitat complexity was recorded as the number of times the habitat unit changed in the 300m reach (i.e. riffle, pool, glide, cascade = habitat complexity of 4).

Data Analysis

Principal components analysis was used to determine those indicators that demonstrated a relationship with the in-stream parameters. Simple linear regression was used to determine if these relationships were significant. The key indicators that came out of this analysis were input into a cluster analysis to determine groupings of the sites. The in-stream parameters that demonstrated a relationship with the five indicators were grouped the same way as the cluster analysis. Kruskal-Wallis and Mann Whitney-U were used to determine if there was a significant difference between the means of these groups. All analysis was conducted on transformed data to increase linearity and variance equality. Percentages were transformed using the arcsine square root transformation and continuous data by taking the log to the base 10.

Results

The initial indicators were reduced to 5 key indicators using Principal Components Analysis (PCA): number of barns per kilometer, percent forest cover at the reach scale, percent forest cover, percent agriculture and percent channelization at the riparian corridor scale (Table 1). PCA was used to select out those indicators that are responsible for the majority of the variation and to show which in-stream parameters the indicators are related to. Further information on PCA can be found in the following sources: Fielding (2003), Jackson (1991) and Pimentel (1979). In the riparian corridor scale two axes were selected based on eigenvalues, percent variance and broken-stick eigenvalues (Jackson 1993). On the first axis percent agriculture, percent forest, percent channelization and dissolved oxygen predominate. Percent pasture and row crop are also important, but for simplicity only percent agriculture was used in further analysis. On the second axis the number of barns/km and ammonia came out together. At the reach scale only one axis was maintained based on broken-stick eigenvalues, eigenvalues and percent variance. On this first axis percent forest, large woody debris and habitat complexity have the highest absolute component scores. Percent agriculture also has similar scores, but percent forest was chosen to represent this axis. Regression analysis between the indicators and in-stream parameters evident in the PCA is presented in Figure 1. All of the relationships are significant and confirm the PCA.

Table 1. Principal components analysis at the reach and riparian corridor scale.

	Reach	Riparian Corridor	
	Axis 1	Axis 1	Axis 2
eigenvalue	4.734	6.558	3.458
% of variance	36.412	46.846	24.698
Component scores			
# of barns/km or 200m	-0.044	-0.106	-0.466
% channelization (only at corridor)		-0.364	0.027
% agriculture	-0.405	-0.311	-0.148
% forest	0.403	0.375	0.042
% shrub	0.069	-0.237	0.268
% pasture	-0.346	-0.310	-0.242
% row crop	-0.284	-0.323	0.215
dissolved oxygen	0.326	0.330	-0.121
temperature	-0.053	-0.280	-0.258
nitrate	-0.044	-0.179	-0.311
ammonia	0.006	-0.122	-0.389
large woody debris	0.393	0.225	-0.354
% instability	-0.200	-0.108	0.171
habitat complexity	0.401	0.259	-0.313

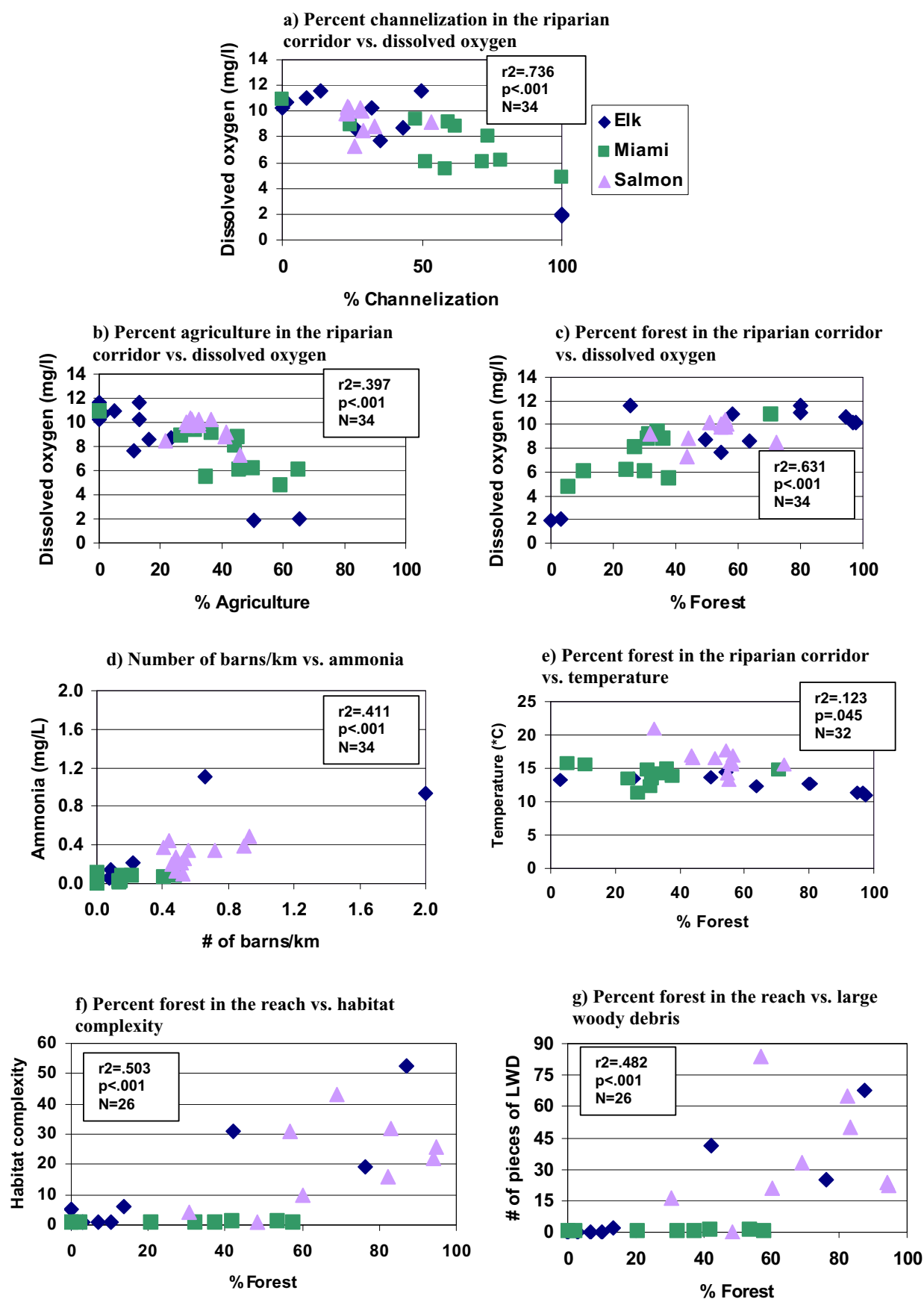


Figure 1. Regression analysis comparing lead indicators and in-stream parameters.

The cluster analysis grouped the 5 indicators into 4 groups. The summary of the key indicators by the 4 groups is presented in Table 2. Group 2 is the least disturbed with minimal channelization, barns or agriculture and extensive forest at the reach and riparian scales. Groups 1 and 3 are quite similar except that group 3 has greater forest at the reach scale. These 2 groups have high levels of agriculture, barns/km and channelization and medium levels of forest at the riparian corridor scale. Sites within group 4 have a moderate level of channelization, the most barns per km and quite a bit of forest at the corridor and reach scale.

Table 2. Mean (\pm SD) of each of the five key indicators grouped using cluster analysis.

Land Indicators (Mean \pm SD)	Groups			
	1	2	3	4
% channelization	56 \pm 32	3.1 \pm 6.1	62 \pm 10	26 \pm 3.2
# of barns/km	0.32 \pm 0.59	0.02 \pm 0.04	0.28 \pm 0.32	0.53 \pm 0.14
% agriculture at riparian corridor	30 \pm 21	0.2 \pm 0.5	45 \pm 10	32 \pm 7
% forest at riparian corridor	36 \pm 26	87 \pm 12	28 \pm 9	52 \pm 9
% forest at reach	3.1 \pm 4.5	48 \pm 33	38 \pm 14	63 \pm 22
N	11	5	7	12

The in-stream parameters these indicators related to were also compared as a method to confirm the cluster analysis (Table 3). There is a difference in dissolved oxygen between the sites with the greatest channelization (1 and 3) and the other two groups (2 and 4). There is a difference in ammonia between the groups with different numbers of barns/km. Those sites with forest at the reach scale had the greatest amount of large woody debris and habitat complexity. For temperature there was only a difference between groups 2 and 4. The sites within group 2 are forested at the reach and riparian corridor scale. In contrast the sites within group 4 are forested at the reach, but generally open at the riparian corridor scale. Analysis of the temperature data by visually comparing site and headwater conditions of the forest cover was used to develop a 6th indicator (Figure 2). From this analysis it appears that the condition of the headwaters has a greater effect on stream temperature than site conditions, such as shading or groundwater.

Table 3. Comparison of the five in-stream parameters grouped by the cluster analysis. Significant differences between mean temperature of four groups denoted by different letters ($p \leq .05$). Means with the same letter are not significantly different.

In-stream parameter (Mean \pm SD)	Groups			
	1	2	3	4
dissolved oxygen (mg/L)	7.5 \pm 3.4 ^a	10.9 \pm 0.5 ^b	7.6 \pm 1.6 ^a	9.5 \pm 0.9 ^b
ammonia (mg/L)	0.26 \pm 0.38 ^{ab}	0.05 \pm 0.03 ^c	0.12 \pm 0.17 ^{ac}	0.26 \pm 0.12 ^b
temperature (*C)	14 \pm 1.1 ^{ab}	12 \pm 1.6 ^a	14 \pm 3.2 ^{ab}	16 \pm 1.2 ^b
large woody debris (# of pieces)	0.3 \pm 0.5 ^a	34 \pm 28 ^{bc}	3.7 \pm 6.2 ^{ab}	33 \pm 28 ^c
habitat complexity (# of habitat units)	1.5 \pm 1.4 ^a	27 \pm 20 ^b	1.7 \pm 1.2 ^a	20 \pm 14 ^b
N water quality (habitat)	11(8)	5(4)	7(6)	12 (10)

With the confirmation of the six indicators using regression, cluster analysis and means testing a buffer assessment was developed (Table 4). This assessment provides an idea of the state of each indicator as well as an overall rating for the site (Figure 3 and Table 5). E7 was rated as good for all indicators. EBD was rated as poor for every indicator. E9 received an overall rating as fair. Most of the indicators for E9 were rated as fair with the exception of the number of barn/km which was rated as good and the percent of forest at the site which was rated as poor. Individual indicators rated as good receive 3 points, fair 2 points and poor 1 point. Individual ratings are summed to provide an overall rating. The overall rating is calculated by adding the rating of each indicator together. Overall ratings for a good rating are from 16-18, a fair from 11-15 and a poor from 6-10. The minimum overall score is 6 and the maximum is 18.

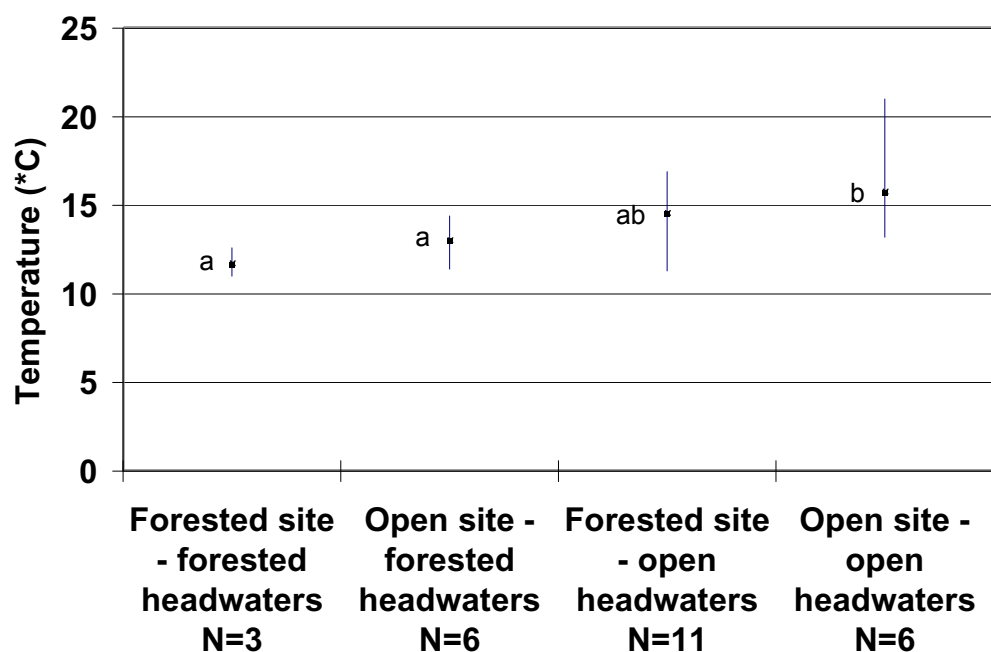


Figure 2. Stream temperature grouped by headwater and site forest cover conditions and differences tested using Kurskal-Wallis and Mann Whitney-U. Significant differences between mean temperature of four groups denoted by different letters ($p \leq .05$). Means with the same letter are not significantly different. Lines represent standard deviation and the N the sample size.

Table 4. Six indicator buffer assessment used to rate stream sections.

Land Indicators	Category		
	Poor	Fair	Good
% channelization	>60	30-60	<30
# of barns/km	>0.6	0.2-0.6	<0.2
% agriculture at riparian corridor	>50	10-50	<10
% forest at riparian corridor	<20	20-60	>60
forest cover headwater/reach	open/open open/forest	forest/open	forest/forest
% forest at reach	<30	30-60	>60

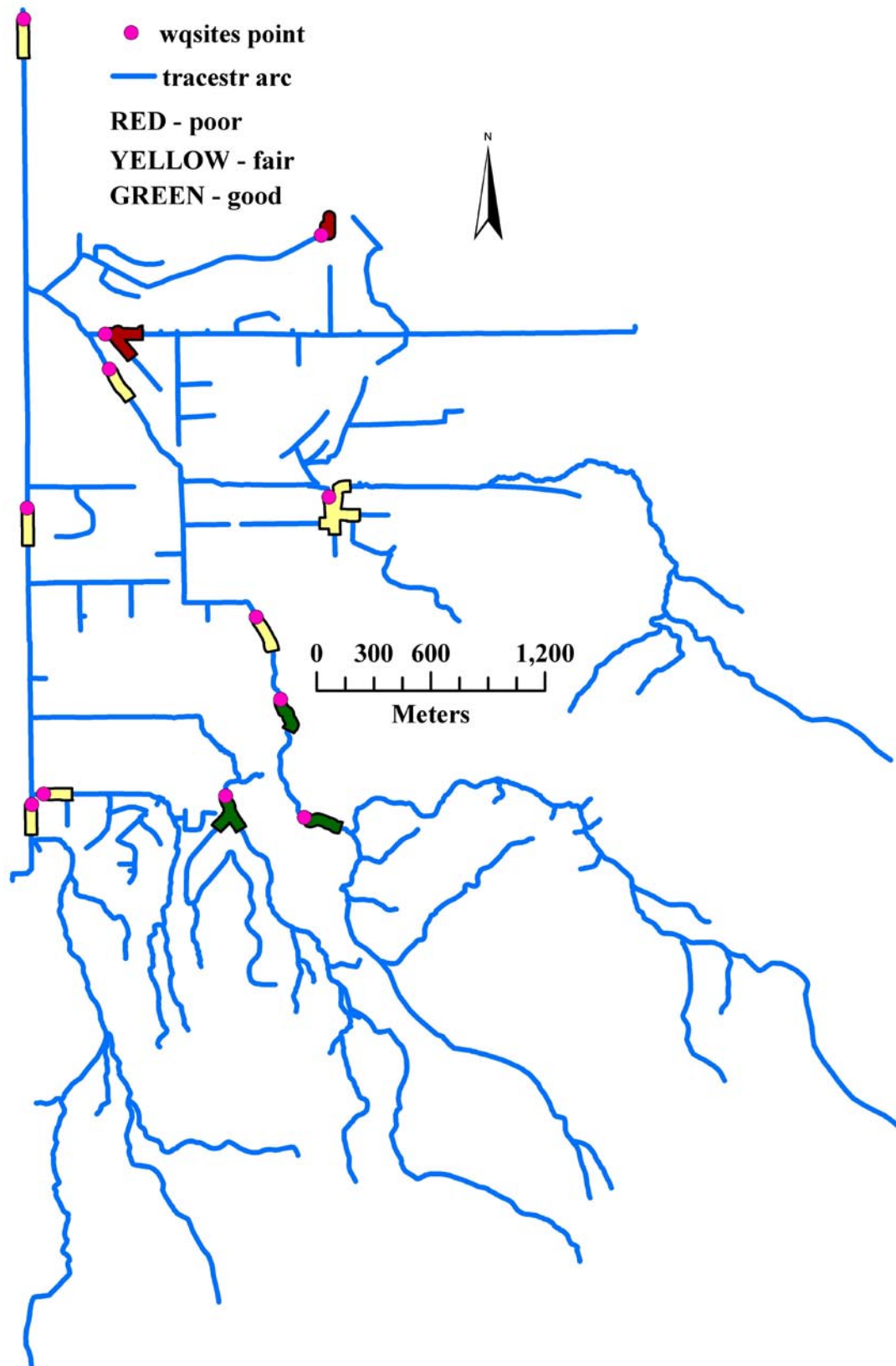


Figure 3. Applications of the buffer assessment to the Elk Creek Watershed.

Table 5. Ratings for the three sites in the Elk Creek Watershed.

Land Indicators	Category	Rating	Points
% channelization	<30	Good	3
# of barns/km	<0.2	Good	3
% agriculture at riparian corridor	<10	Good	3
% forest at riparian corridor	>50	Good	3
forest cover headwater/reach	forest/forest	Good	3
% forest at reach	>60	Good	3
Overall Score		Good	18

Land Indicators	Category	Rating	Points
% channelization	30-60	Fair	2
# of barns/km	<0.2	Good	3
% agriculture at riparian corridor	10-50	Fair	2
% forest at riparian corridor	20-60	Fair	2
forest cover headwater/reach	forest/open	Fair	2
% forest at reach	<30	Poor	1
Overall Score		Fair	12

Land Indicators	Category	Rating	Points
% channelization	>60	Poor	1
# of barns/km	>0.6	Poor	1
% agriculture at riparian corridor	>50	Poor	1
% forest at riparian corridor	<20	Poor	1
forest cover headwater/reach	open/open open/forest	Poor	1
% forest at reach	<30	Poor	1
Overall Score		Poor	6

Discussion and Conclusion

This research supports the importance of looking at multiple scales when managing riparian and adjacent areas with respect to physical in-stream habitat and water quality. At the local scale the riparian area provides woody debris, which plays a role in the creation of diverse habitat. At a larger scale riparian vegetation shades the stream corridor and intercepts nutrients from agricultural practices. These results support Frissel et al.'s (1986) theory that there is variation in the appropriate scale to study depending on the riparian buffer function being studied.

Matching Frissel et al.'s (1986) speculation stream temperature in this study showed a stronger relationship with the riparian corridor than reach conditions. High stream temperatures can alter morphological characteristics of salmonids during egg development, cause direct egg mortality and increase a fish's metabolic rate (Beschta et al., 1987). Collier et al. (1995 cited in Wegner 1999) noted that generally, protecting or restoring headwater streams will achieve the greatest temperature reduction. Streams with small discharges and exposed surfaces will experience the greatest temperature increase (Beschta et al. 1987). This increase is most notable in small headwater streams. It is unlikely that shade will significantly cool a stream once it passes into a shady reach unless cooler inflows occur. Without cool groundwater inflow temperature increases from each exposed reach will not decrease noticeably through the shaded reaches and the result is a stair-step temperature increase in a downstream direction. Although groundwater did appear to cool reach areas in this study the cooling did not extend further downstream where other warmer tributaries entered the main stream. A reach based study in British Columbia found that stream water cooled 170-200m into the forest after passing through a clear cut (Moore and Story 2001). Researchers speculated that this was due to the inflow of cool groundwater. It does not appear that this study investigated temperatures on a watershed basis.

Temperature increases can lead to decreases in dissolved oxygen (Allan 1995). Low dissolved oxygen levels affect salmonid survival and development. A study in the Elk Creek Watershed on cutthroat trout and crayfish in the lower watershed downstream of agricultural influences showed elevated stress indicators such as mixed function oxygenase induction and reduced swimming performance (Sekela et al. 2003). Results are suspected to be linked to low dissolved oxygen levels. The increase of agricultural land uses and the subsequent decrease of forest cover for shading at the riparian corridor demonstrated an effect on dissolved oxygen.

Channelization was also found to be strongly related to dissolved oxygen. Channelization is the alteration of a stream channels bank slope, gradient, width, depth or direction (Bolton and Shellberg 2002). In agricultural areas, stream channelization typically occurs to drain adjacent land in order to increase the amount of arable land and for flood control. The effects of channelization can be both physical and biological. Few studies have directly examined the effects of channelization on water quality parameters such as oxygen and nutrients (Brookes 1988). The majority of studies on channelization have examined the physical effects such as bank stability, water flows and habitat diversity. The reason for the strong relationship between channelization and dissolved oxygen is likely due to a mixture of factors related to the initial physical changes. For example, the decrease of riffles, stream bends and wood in the stream where turbulence occurs could increase mixing. The decrease in shading that typically accompanies stream channelization can result in increased macrophytes filling in and catching sediment consequently decreasing stream flow. Similar sedimentation and aquatic vegetation growth was seen in a New Zealand study of channelized and unvegetated pastures (Boulton et al. 1997 cited in Bolton and Shellberg 2002). No direct studies of channelization versus dissolved oxygen were found. Although Wang et al. (1998) reported that variation in index of biotic integrity (IBI) scores in low-gradient Wisconsin stream was explained by channelization, total in-stream habitat and time since the channel was modified. An index was developed from this study. The researchers similarly rated streams that had >60% channelization as poor.

Wang et al. (1997) noted similar results to this study of significant agricultural impacts noted after agricultural land uses increased above 50%. Wang et al. (1997) had some sites that had greater than 80% agriculture land use with good habitat quality and biotic integrity. These "good" sites had relatively high gradients, rocky substrates, and had not been channelized. Percent agriculture appears to be a weaker indicator of stream health likely due to variations in agricultural practices and intensities. Therefore, an additional indicator representative of agricultural intensity, the number of barns per km., was included.

The number of barns in a watershed is not a commonly used indicator. Livestock density has been used more often. Direct linkages have been demonstrated with higher stocking densities and increased nutrients in the stream (McFarland and Hauck 1999; Wernick et al. 1998). However, these measurements can be quite time consuming to estimate. The number of barns/km provides a rough estimate of the amount of manure that could have an effect on adjacent streams even if a portion of the manure is exported. Using the number of barns as an initial estimate provides an idea of where best management practices should be first investigated. This assumption was supported in the Salmon River Watershed

where the highest ammonia levels, greatest number of barns and the most extensive buffer system were seen. This is likely related to a few different factors: well drained soils contributing nutrients to the stream; open headwaters carrying nutrients to the stream with downstream buffers having little effect; and direct piping of agricultural drainage systems may be carrying nutrients directly into the stream bypassing the filtering capacity of the buffer (Stauffer et al. 2000).

All of the water quality parameters including ammonia, dissolved oxygen and temperature showed a relationship with the riparian corridor scale. In contrast, habitat conditions were most strongly related to forest cover at the reach scale. The importance of the forest cover at the reach and the associated minimal movement of wood along the stream channel is likely because the majority of segments sampled are low gradient and small in width (Bisson et al. 1987). The presence of large woody debris (LWD) plays a crucial role in the formation of habitat diversity. Wood in a stream forms pools where salmonids can rest, captures sediment and provides cover for young salmonids (Murphy et al. (1985 cited in Bisson et al. 1987). In a local scale agricultural study Talmage et al. (2002) found a positive correlation between the percentages of sand and woody debris, but negatively correlated with the percentage of run habitat. The presence of riparian forests to supply LWD and consequently diversify stream habitat is essential. Similar to this study May et al. (1997) found LWD of a significant frequency only in stream segments with >70% of the riparian buffer >30m wide. They also found habitat complexity was related to riparian cover. Stream segments with >50% of their surface area as pools were found only in reaches with $\geq 60\%$ of the riparian buffer >30m wide.

All of these indicators together provide an indication of the state of the land and in-stream conditions. By incorporating them into a buffer assessment an indication of reach and riparian corridor conditions can be ascertained and initial protection and restoration recommendations can be made. As an example the ratings for three sites in the Elk Creek Watershed can be used to demonstrate restoration and protection priorities that can be noted from the assessment. The conditions of E7 are contributing significantly to downstream conditions. This area should be maintained. It requires less effort to protect an area than to restore an area. In contrast EBD was rated completely as poor. Active restoration, in-stream structures, channel and streambank configuration and planting programs, should be focused in areas where conditions are better and restoration will likely be more successful (Kauffman et al. 1997). However, passive restoration, stopping anthropogenic activities that are causing degradation or preventing recovery, should be employed, such as the appropriate storage and application of manure. E9 could be enhanced with the planting of trees and the placing of in-stream wood at the reach scale. If additional barns are considered for the area upstream of E9 the use of best management practices should be ensured. The riparian buffer assessment allows restoration to be focused in areas and on characteristics that can be most easily and successfully restored. Riparian buffers that are currently effective can be highlighted for protection. The riparian buffer assessment tool would be most relevant when linked with information documenting areas of current or historical salmonid use, obstructions to habitat access, future planning and landowners interested in participating in restoration projects.

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